Besprechungen

J. E. Doran and F. R. Hodson, Mathematics and Computers in Archaeology. Edinburgh University Press, 1975, 381 pages.

This book is not a 'Statistics for Archaeologists' or even 'Numerical Methods for the Uninitiated'. Such books remain to be written und readers will just have to wait if they need them. Rather, this is a book containing a thoughtful discussion of a number of mathematical techniques which interest the authors. The reader who really wants to know what is going on will have to read many of the references if he is really to appreciate the subtlety of the critique. In the preface, one of the authors states very clearly that within this subject readers must be prepared to think and judge for themselves. This reviewer must add the warning that both authors have their special interests and preferences, and that this is decidedly reflected in the choice of topics for the text. However, their judgement is based on considerable experience and it is to be valued highly. Their views are not the only ones on these topics. It would have been useful had the authors suggested a few key references at the beginning of each chapter, but this has only been done in a few places.
The great difficulty in writing a text of this kind is that in a way, an author must be a little like a magician who always holds something up his sleeve leaving many things half said or implied. This is because of limitations of space or because so many different concepts impinge upon each other. The reader will have to accept that the book is to be reread several times, with pauses to consult the references. Archaeologists are not used to this kind of text and this way of reading it, but there is no other way.
The book is a very good antidote to Clarke's 'Analytical Archaeology' which was reviewed here earlier (Bonner Jahrb. 170, 1970, 469 ff.), and it contains a very detailed professional criticism of the 'New Archaeology' which was much in favor in the USA. It tells what really can be done with mathematical methods in certain fields and more importantly still, what cannot be done.

Hodson notes that the 'New Archaeology' is not equivalent to a quantitative method, and he disclaims any association with this school, which he calls a 'bizarre mixture of naivety and dogmatism'.
The introductory chapter is by Hodson, and it prepares the archaeologist reader for the subject in quite a clear fashion. He discusses the origins of interest in mathematical methods in archaeology and mentions early attempts at seriating data as an example. Seriation, or the arrangement of find complexes in chronological order, has been done by hand successfully since Montelius and Flinders-Petrie, but large find groups are quite tedious to deal with.
Hodson makes a useful distinction between raw empirical data, classes defined from such data, and the interpretation of such classes in terms of people. He proposes to deal only with the first problem, und does not touch on the second.

The second to fourth chapters are by Doran und are intended to provide some mathematical foundation and an introduction to elementary statistical methods for the a-numerate archaeological population. Doran describes mathematics as 'The art of giving the same name to different things (abstraction)' with the requirement of rigorous proof, the most fundamental characteristic after abstraction. Next, he discusses sets and graphs, the non-numerical character of which characterizes much of mathematics. Archaeologists are not usually aware of this. This is followed by a treatment of numbers and vectors which is quite clear provided the reader knows a bit about the matter beforehand and has remembered something of what he had been thaught in school. Variables, constants and arrays follow. The definition of the important concept of an algorithm is given as 'a precisely specified sequence of computations or more generally actions, designed to bring about, or find some desired result'. Geometry and distance concepts are introduced and the relationships stated between algebra and geometry. Doran notes that 'data analytic methods are essentially algebraic but are largely motivated and understood by way of geometric insights' and it is these methods which most concern archaeologists. In later chapters where such methods are discussed in detail by Hodson, it is sometimes forgotten to provide the useful geometric aid to understanding which Doran suggests. One sometimes has the impression that the authors did not always coordinate their efforts as much as might have been wished.

Doran introduces the concept of distance, discussing the most familiar Euclidian distance of everyday life, and follows this by the introduction of metric and triangle inequalities. This is followed by a discussion of the ultrametric inequality which plays such an important role in certain data analytic techniques. The discussion is insufficiently detailed for the non-specialist reader who ought to be told about Sibson's treatment of the subject here (R. Sibson, Order Invariant Methods for Data Analysis. Journal Royal Statistical Soc. 34, 1972, 311 ff.). In that paper, good graphical illustration makes the question quite understandable, even for the nonmathematical reader. Doran notes the important case of inverse distance, i. e. given a table of numbers, find a set of points in rectangular coordinates having those distances, which occurs frequently in archaeological problems where dissimilarities between assemblages must be described numerically. Mathematical models are then described as 'an attempted specification in exact mathematical terms . . . of the variables which characterize a real world situation or process, and of the relationships between them'. This is done in order to gain information about the process or through more facile manipulation of the data.

Chapter three is devoted to elementary probability theory and statistical inference. Doran adopts what is called in statistics a 'Bayesian' emphasis. Bayes was one of the founders of mathematical statistics in the 18th century. The Bayesian view is not shared by a majority of professional statisticians, but it is nonetheless coming into fashion among workers in problems of pattern recognition. The essence of the outlook is summed up in Bayes' Theorem. This theorem is not explained by Doran in a clear fashion for the untrained reader. The reviewer suggests that it might be described as an optimum way of placing a boundary line between two overlapping statistical distributions. This allows a decision to be made as to whether a given result belongs to one distribution or the other, but it depends on prior knowledge of the nature of the two distributions. It is the element of prior knowledge which most modern statisticians object to, but this point need not worry us here. The misprint on p. 35 line 9 in the text which should read P (H_1/E) in the essential equations introduces some forther confusion. A simple illustration of overlapping distributions with a decision boundary would have helped.
Next follows a description of the concept of a random number. The idea of a number taken modulo 65536 is introduced without explanation, and why such an odd number should be of interest is not stated and 'modulo' not explained. Modulo means remainder after division and 65536 is a number of some significance on computers, since it is 2 raised to the 16th power. The following discussion of random digit sequences is quite weak and probably hard for the untrained reader to follow. A much better and subtle explanation of random numbers, written for the layman can be found in an article by G. J. Chaitin which appeared after the printing of the book (Scientific American 1975, 47 ff.). The interested reader should consult it.
Doran's treatment of scales of measurement contrasts in its clarity with the rather turgid explanation of random sequences. Descriptive statistics are treated summarily, and the concepts of mean and standard deviation are introduced using formulae containing symbols which are not explained for the uninitiated as they should have been. The idea of squaring distances from the mean in such formulae, which have really rather subtle reasons behind it is explained simply as being 'least inconvenient'. There is no obvious reason as to why this should be less inconvenient than taking the absolute value (without regard to sign) of the distance. A simple method for calculating the variance and the mean is noted but not explained. Here the reader should consult the explanation in R. A. Fisher's classic work (Statistical Methods for Research Workers [1958] 46 ff.), but the reference is not cited by the authors. A description of probability distributions, samples and populations follows. In the discussion of sampling distributions, the way to get from a frequency distribution to a probability distribution is not explained. An equally unclear explanation of maximum likelihood follows. The discussion of theoretical population distributions is inadequate in terms of explaining the way in which the transitions between the various distributions come about. No adequate references to these matters are given, although they are quite important. Estimation, significance tests, and non-parametric techniques are mentioned. The sign test is noted, but the very simple calculation is not shown. The extremely important χ^2 test is skimmed over without detail, and only a reference to S. Siegel, Nonparametric Statistics for the Behavioral Sciences (1956) is given. The German speaking reader should refer to the excellent small manuals by J. Pfanzagl, Allgemeine Methodenlehre d. Statistik (1967–1968) for all of these matters, or to the still clearer volume by G. Claus and H. Ebner, Grundlagen d. Statistik für Psychologen, Pädagogen u. Soziologen (1972).
Doran notes quite rightly that 'in archaeology it is rarely possible to perform controlled experiments', and therefore 'in such circumstances it seems quite unrealistic at the present time to expect to use formal methods of statistical inference in more than a very peripheral manner'. The mathematical methods of most use in archaeology are restricted to the techniques known as 'data analysis'. However the archaeologist should have some understanding of elementary statistics, in the reviewer's opinion, if only to know when not to use them.
Doran introduces concepts of more than one random variable, leading to the ideas of multivariate statistics. He uses the bivariate histogram and the concept of covariance as a measure of the degree of non-independence, and leads up to the concept of the linear correlation coefficent in a very understandable way. Unfortunately there is no review given for the matrix algebra used in multivariate analysis, although an attempt is made to explain analysis of variance techniques which depend on it. It would have been possible to give a summary in the appendix for those readers who were not exposed to the subject in school, or, to give an appropriate reference.

Then follows a section on the statistical aspects of radiocarbon dating which appears quite out of place in this chapter. In the text it is stated initially that statistical methods used in sciences ancillary to archaeology are not the subject of the book, but this is not followed consistently. However, the concluding remark in the chapter is worth repeating: 'the aim has been less to equip the reader to use the methods which we have described than to provide a conceptual framework within which their nature and sound use can be understood'. This is followed by a bibliography which probably should have been given at the beginning of the chapter.

Chapter four is a detailed discussion of the operation and concepts used in computers. It is, in the reviewer's opinion, the weakest in the book. It is not a balanced view of the subject and is already badly out of date. In this rapidly changing field, it is difficult to write a generalized description which will remain a valid picture for more than two years. Perhaps the time delay between preparation of the manuscript and the publication may excuse the one-sided treatment. For example, Algol is introduced as the prime example of a computer high level language, although this language is much more rarely used than is Fortran in the scientific world, and it is not even available at many computer installations. PL/1 which is beginning to replace other languages at many installations is not mentioned.
As an example of programming, the creation of a picture on the line printer of the computer is given in great detail. At most computation centers, such techniques are only used for rough approximations and a proper plotter used for much clearer results. In newer installations the user has a terminal which is usually capable of displaying graphics directly. Probably an example of the straightforward mathematical calculation of one of the methods already discussed would have been equally illustrative. Typical of the 'up the sleeve' approach mentioned earlier, the concepts of 'compilers', the special programs which translate the high level language into machine instructions are introduced after the idea of a high level language, rather than before. The procedure really used, namely the creation of an executable program through linking the results of compilation to library program modules and to the computer's operating system programs is not mentioned. Discussion of access to machines restricted to punched cards or typewriter-like terminals is outdated. No mention is made of video terminals or mini- and micro-computers which are now coming to dominate things.
There is useful discussion of the relationship between mathematics, statistics and the machine, but the suggestion made by Doran that the reader should browse through the latest computer science conference publications for up to date information is, to say the least, expecting a bit much of the reader for whom the book is intended. The reviewer suggests that the reader definitely abstain from any such effort, which will only confuse him terribly. The whole chapter is rather vague, as if the author had to treat much too big a problem in much too small a space. A really good popular and readily understood book on the operation of computers remains to be written for the layman.

Chapters five through eight, written by Hodson, form the heart of the book in the reviewer's opinion, and they are by far the best part of the whole. Many of the methods which have actually been used in archaeology are treated in considerable detail by one of the few archaeologists who has had wide experience in such matters. It is also evident that he is used to explaining such things to archaeologists, for little is taken for granted. However, one must be prepared to read the references in order to understand everything.
Hodson introduces the data matrix: 'the translation of archaeological material into a descriptive numerical language that can provide a starting point for its presentation and analysis'. The contents of the matrix or array of numbers contains either information about the presence or absence of attributes in an item, or real numbers related to its dimensions, or some kind of proportional count, where the items may be objects, graves, strata or assemblages. The essential fact that one cannot mix items having different properties in this kind of an array is brought out clearly, but the subjective quality in assigning values to the items is not stated strongly enough. The aim of analysis of data is clearly presented as a sequence starting with the 'sample' and leading to a 'target' where partial discovery influenced by partial survival gives a partial reflection of a whole human society. Put more simply, the reviewer would say that archaeology, as normally practiced, consists of the art of drawing nearly correct conclusions from apparently inadequate evidence, the correctness being confirmed by subsequent discovery of new evidence which fits the proposed pattern. Mathematical methods as discussed by Hodson try to emulate this technique as far as is possible. In practice, the subtle workings of the human mind when dealing with fuzzy criteria are very hard indeed to emulate in a machine.
Much of formal statistics is concerned with tests of the significance of the departure of some parameters which describe some data assemblage from those of a hypothetical assemblage or from another real assemblage. Hodson correctly notes that such procedures are seldom useful in archaeology. Statistical procedures are mainly used to describe and summarize data und to suggest hypotheses or relationships, but in archaeology they cannot estimate parameters for hypothetical parent populations in the context of standard statistical theory. The reviewer sees this problem as similar to formal classification theory, where a distinction is made between so-called supervised and unsupervised learning techniques. In the supervised technique there is a teacher (who may make mistakes) or a set of known classes with known properties, and it is a problem to assign other data to the classes in question. In the unsupervised technique, the classes are not known in advance and the problem then becomes deducing them from the data itself.

Hodson gives considerable space to the choice of attributes which enter into the data to be processed. He underlines the 'choice between what the archaeologist sees and quite other factors that conditioned its (the object) manufacture'.
In distinguishing between attribute and attribute state Hodson follows N. Jardine and R. Sibson, Mathematical Taxonomy (1971), a work which will be beyond most archaeologist readers. Descriptive terms which are mutually exclusive are opposed to an actual specific score or numerical value placed on the terms. This is equivalent to the distinction between the use of an identifier or name, called a variable, and the value which the variable may take. In consulting the archaeological literature dealing with such questions, Hodson notes that there is a great deal of confusion about such matters. He proposes the useful idea of a hierarchical list, beginning with broad categories, decomposing these into parts, further decomposing them into a set of decorative or structural motifs and finally describing these in presence absence or measurement terms. For stone tools Hodson favorably appraises the analytic description of type by Bordes and his followers, giving intuitive attribute lists as a result. For pottery, similar methods have been the daily bread of archaeologists for a century. Hodson allows himself a snide remark about the late Bohumil Soudsky's claimed improvement over such classification techniques. The reviewer agrees. Hodson thinks that metalwork is the best material for analysis, since many objects are found in a complete state, they are usually made by specialists in a highly controlled medium and the craftsmen's intention is clearly revealed. However the reviewer must note that types may traditionally persist for much longer than ceramic forms, and that metal objects have much longer periods of use and survival after manufacture. Hodson's own work on the material from the La Tène cemetery at Munsingen serves as the basic example. This case is about as ubiquitous in the archaeological statistical literature as is Fischer's Iris data in other areas of statistics. What Hodson does not say is that a site with material in as easily analysed condition as that of Munsingen is unfortunately a great rarity. Most sites or collections of objects are far less well behaved.
Summarizing, Hodson defines types by 'eye' or on a more detailed level by tool classes or primary types. The contents of assemblages are described by counts of items present, or simply by noting presence or absence. Alternatively, counts of items attributed to given classes can sometimes be useful and, occasionally the physical dimensions or weight can be used. A fourth possibility is a count of artifacts which cross-cut defined types, or any combination of all four. Any counting scheme depends on the consistency of recovery in an excavation especially when proportions are calculated, and therefore is to be used with caution. Whole categories of things must be excluded from analysis if older excavations with minimal find control und fragmentary museum survival are considered.
A long section is devoted to the question of presentation of data. Hodson notes the importance of visual display as opposed to lists. Anyone who has ever been faced with the inordinately long lists which some archaeologists use to decorate their works knows how little use these things are when trying to interpret the results. They are, of course, a means of presentation of basic data, should anyone want try some calculation. Hodson's critique of the bar chart technique and the cumulative graph beloved of the Bordes school in paleolithic studies is excellent. Finally someone has come out and said in print that the emperor wears no clothes. The reviewer, in a thesis presented in 1958 said the same thing, but he didn't have the good sense to publish this part of the work at the time. Hodson notes the fundamental weakness of the cumulative graph in that its appearance depends highly on the ordering of the underlying attributes. Hence the ability of the eye to appreciate differences is affected. Bohmers previously noted that differences at both ends of the chart are less noticeable than are those in the middle, and Hodson suggests that clustering techniques applied to Bordes' data would be much more effective in displaying differences between various paleolithic assemblages.
Histograms are similarly treated by Hodson, who notes that the ordering of the X axis is an essential aspect of the ultimate appearance of the figure. The baseline can be grouped so as to reveal characteristics where one dimensional scatter diagrams and cumulative histograms usually hide them. Presence of more than one underlying population in the sample or formally speaking, indications of bimodality are very subject to the sampling errors always gravely present in archaeological material. Here too, cluster analysis is a more reasonable approach. Attempts to fit some kind of mathematical distribution to skewed archaeological data are frequent, and are deplored. Scatter diagrams, except for very simple two dimensional examples, are usually more confusing than helpful, and Hodson notes that sophisticated multivariate techniques are much better. Most archaeologists are unaware that such techniques exist, and it is one of the great merits of the book under review to call their attention to the fact.

Chapter six is devoted to a detailed discussion of measures of similarity and correlation. It does not repeat the very detailed treatment of P. H. A. Sneath and R. R. Sokol, Numerical Taxonomy (1973) which should be read by every archaeologist, but leans heavily on this important work. Hodson argues convincingly that the way in which similarity is measured, and the corresponding introduction of a distance function with dissimilarities transformed to distances is a most important matter. It is usually settled by trial and error, lacking other criteria. He mentions Sibson's introduction of ranking rather than actual metric distances, i. e. arranging things in a sequence with order numbers rather than rational numbers (op. cit.), but he seems to think that it is restrictive and unhelpful in practice. The reviewer thinks that Sibson's method is highly attractive theoretically. It is

most suitable for data which is likely to contain a high proportion of error due to unknown causes, but of course it leads to much more complicated and less efficient calculation. Hodson notes that if numerical distances are considered, then the data should be so prepared that the calculation of a distance function produces values with ratio properties. Otherwise misleading results in multivariate analysis may result. D. J. Kendall, however, has produced quite good results with measures which are very crude by this standard (Incidence Matrices, Interval Graphs and Seriation in Archaeology. Pacific Journal of Mathematics 28, 1969, 565 ff. – Abundance Matrices and Seriation in Archaeology. Zeitschr. f. Wahrscheinlichkeitstheorie 17, 1971, 104 ff.). Standardization via division by the standard deviation, the range or by logarithmic transformation is suggested by Hodson. If Euclidian distance measures are used, there may be considerable justification for such steps – for reasons which are too complicated to be discussed here.

Hodson mentions the 'city block' metric (distances as sums of absolute values rather than root sums of squared values and notes the relation between this and the early Robinson 'coefficient of agreement'. The simple Kendall count of common types is criticized as being useful only when there is no great variation in the numbers of types per assemblage, although correction for this is relatively easy as Kendall himself has suggested. Sokal and Sneath recommend a simple matching coefficient, in which the number of positive and negative matches is a proportion of the total number of valid comparisons between two items, with 'don't care' cases not counted. This coefficient weighs quantitative attributes higher than qualitative ones, depending on the number of ways in which the quantitative ones can be divided. The Jacquard coefficient, where negative matches are ignored, and where valid comparisons are used as a normalizer is recommended as well, and a simple clear formula for it given. When the logarithm of the Jacquard coefficient is taken, this becomes Bordaz's Tanimoto distance. But for Hodson, the most sensible of all these attempts to normalize similarity coefficients is that of J. C. Gower (A General Coefficient of Similarity and Some of its Properties. Biometrics 27, 1971, 857 ff.) which he believes copes with most disadvantages. Gower's coefficient is applicable to presence/absence, qualitative and quantitative attributes. For the first case it reduces to the Jacquard coefficient. The greatest advantage of the Gower coefficient is that it allows the use of mixed kinds of attributes in one array.

Hodson warns against the use of correlation coefficients as similarity measures, and quotes C. A. Goodman and W. H. Kruskal's rejection of χ^2 like statistics as measures of association (Measures of Association for Cross Classifications. Journal Am. Statistical Assoc. 49, 1954, 737 ff.). The French school of statisticians is however much addicted to this approach. Correlation values are biased in favor of large or rare categories and they probably shouldn't be used, if only for this reason. E. M. Wilkinson whose doctoral thesis seems to have been unknown to the authors at the time the book was written has dealt quantitively with the problem of obtaining maximum likelihood solutions in seriation and has shown that extreme variation in the richness of the analysed units make solution impossible (Techniques of Data Analysis, in: Archaeo-Physika 5 [1974] 1 ff.). Practice has shown that rich single assemblages tend to dominate any seriation, both mathematically and in normal intuitive archaeological thought. Common sense should tell us that this is probably not a good thing, but we do it anyway.

The author also touches on an interesting problem which appears frequently when dealing with cemeteries and other types of archaeological assemblages spread out in space, and where this information may be significant. The position of graves in a cemetery, where the earliest graves start around one or more nuclei and the rest are placed in ever increasing distances from the center, though not in a geometrically well defined pattern, comes immediately to mind. The eye of the observer readily interprets this 'horizontal stratigraphy', but tests of significance based on distances turn out not to work too well. Hodson makes no really useful suggestions as to how to include such data in an analysis. The reviewer once tried to cope with the problem. The idea was to assume that one knows the earliest grave in the assemblage. Radii at equal angles were drawn from this grave to the outer limits of the cemetery. These were divided into equal intervals and contours are drawn between the interval boundaries. It is supposed that those graves enclosed in identical interval boundaries are close in age. Therefore if two graves share the same interval they are given a higher matching coefficient than if they share adjacent or distant intervals. This kind of distance weighting unfortunately assumes a uniform cemetery growth and applies only to the single nucleus case. But it shows how one might go about solving the problem of weighting the matching coefficients for the graves by location. A less global solution might simply lie in raising the matching coefficient for graves which lie near each other. Such methods are fraught with danger if the cemetery has a multiple nucleus or if the assumption concerning the earliest grave is wrong.

Chapter seven is Hodson's treatment of the problem of automatic classification, 'with methods for transforming the unmanageable mass of individual units that form the basic archaeological record into a coherent body of information'. Since biologists have been doing this sort of thing for a very long time, it is natural to look to that field for aid. Taxonomy, and ultimately numerical taxonomy originates in biology. It is interesting to note that an emphasis on hierarchy is immediately introduced by implication. It is quite possible to classify without assuming some sort of hierarchy however. For his treatment, Hodson follows the work of R. M. Cormack (A Review of Classification. Journal Royal Statistical Soc. A 134, 1971, 321 ff.) which summarizes much of the literature up to 1971. For the traditional european archaeological viewpoint, Hodson quotes V. G. Childe, Piec-

ing Together the Past (1956) and then goes on to various american authors. Numerical analysis of attributes leading to a classification is but an attempt to do what archaeologists have done intuitively for over a century. 'All numerical methods', says Hodson, 'are considered by us as experimental and most as unsound numerically and inappropriate archaeologically'. That should discourage the reader, but don't lose heart: A. C. Spaulding (Statistical Techniques for the Discovery of Artifact Types. Am. Ant. 18, 1953, 305 ff.) introduced χ^2 as an association measure and defined types as a 'non-random attribute cluster' which, says Hodson, 'has become a major element in the mythology of the New Archaeology' in the USA. The basic objection is that attribute clusters are not necessarily the essence of types. The so-called matrix analysis of D. J. Tugby and D. L. Clarke (Tugby, A Typological Analysis of Axes and Choppers from Southeast Australia. Am. Ant. 24, 1958, 24 ff. – Clarke, Matrix Analysis and Archaeology. Nature 199, 1963, 790 ff.) is mentioned as inappropriate since it utilizes what is essentially a seriation technique of the Brainerd-Robinson type on a square similarity matrix composed of counts of the numbers of times traits occur together. This is a procedure which gives common traits very high counts. Archaeologists do it instinctively all the time. It is a classic example of how to muddle things with mathematics if applied quantitatively. A more subtle muddling in attribute cluster analysis is J. R. Sackett's attempt to remove the difficulty by using a χ^2 based measure (Quantitative Analysis of Upper Paleolithic Stone Tools. Am. Anthr. 68, 1966, 356 ff.). Hodson provides a very clear counter-example in his figure 7.1 which results in rejection of this technique. Here the types which emerge are directly produced by the method itself. Attribute and matrix analysis as understood by the American school are rejected as valid approaches in taxonomy, since they embody specific statistical misconceptions.

A clear example of the taxonomic problem is illustrated by assuming that 300 hand axes lie on a table. Alternative hand strategies for classifying them are to be tried. The strategies proposed are: 1. agglomerative hierarchical, 2. divisive, based on a single feature, 3. relocation to provisional distinctive type specimens, and 4. combinations of the previous three. This example is illustrative of some well known methods. A discussion of single link or nearest neighbor clustering, complete link or furthest neighbor methods, and average linking is given with the example. It is astonishing how many researchers continue to reinvent these methods or use them intuitively. More recent and subtle intermediate techniques like the shared near neighbors method of R. A. Jarvis und E. A. Patrick (Clustering Using a Similarity Measure Based on Shared Near Neighbors. IEEE Transactions on Computers, C 22, 1973, 1025 ff.) were not available at the time the book was written, and probably published in a place where the author might not have looked. On the whole, there is an enormous body of literature concerning these matters, and a number of books on the subject as well. They deserve to be mentioned here for completeness: M. Anderberg, Cluster Analysis (1973); B. Everett, Cluster Analysis (1974).

Hodson feels that divisive methods are not good, but that the 'k-means' procedure is favorable. Its advantages include the fact that it can be done in a small amount of computer memory space, and that the clusters are characterized by the average value of a score relative to each attribute. The method minimizes the sum of the squared error between each unit and the cluster centroid to which it is assigned, by means of what is called a hill-climbing algorithm. This technique searches for an optimum stable situation in the data, and stops by itself. Hodson notes the danger that such techniques can be trapped in stable local minima which do not represent 'true' clusters. The likelihood of finding the true global minimum decreases as the number of units considered increases. Hodson mentions, but does not discuss in detail, the problem of knowing how many clusters should be considered in other than k-means methods, and refers to 'external evidence'.

To avoid the effects of linear transformations on the data, i. e. the effects of the scale used in making original measurements on objects to be classified, Hodson recommends the use of a distance measure due to the statistician Mahalanobis. He merely gives a reference to the following chapter, but there is no further information in how this is calculated in either place. Mahalanobis distance is not too complicated if viewed geometrically, and the illustration figure 2.7 in R. O. Duda and P. E. Hart (Pattern Classification and Scene Analysis [1973] 25 fig. 2,7) clarifies things even for statistical novices. It should have been pointed out that the Mahalanobis distance usually applies to multivariate normally distributed variables, but we already know that very few archaeological classifications concern measurements where this can be assumed. This hidden assumption of statistical normality may be missed by the unwary archaeologist. There must always be very good reason indeed to believe that statistically normal distributions are somehow involved in an archaeological problem before methods based on them are chosen.

Chapter eight is devoted to other methods of multivariate analysis, concentrating on principal component, principal coordinate, factor, discriminant and multidimensional scaling techniques. Hodson refers to J. B. Kruskal (Multidimensional Scaling by Optimising Goodness of Fit to a Nonmetric Hypothesis. Psychometrika 29, 1964, 1–27; 115–129) and to Gower (op. cit.) if the reader wants fuller mathematical details. His explanation is geometric, showing how the first three techniques are equivalent to rotations in a multidimensional space. He fails to note however, that all the methods are describable in terms of linear transformation theory: rotations, translations and scale changes in multidimensional space. Such methods are quite powerful und well understood in modern mathematics. They are also equivalent to linear matrix operations or to solutions of sets of linear equations. They are capable of considerable sophistication, and there is an enormous literature devoted to them.

Most computing centers can supply whole libraries of programs for methods of this type, but users must really know what they are doing and not apply things blindly. Rapid techniques, not mentioned by Hodson, are available when the matrices are sparse, that is when many elements are zero. The really subtle difference between the linear methods and non-linear methods were made clear in Sibson's classic paper (op. cit.). Essentially, the linear methods are rigid rotations, translations and scale changes, while non-linear methods are non-rigid order preserving transformations. Sibson's explanation supplemented by Gower's comments which appear in the appended discussion to Sibson's paper should be read. The stiffening effects of Kendall or Sibson transformations were noted in a recent paper which shows how the two types of technique can be made to approach each other (I. Graham, P. Galloway, I. Scollar, Model Studies in Computer Seriation. Journal Arch. Science 3, 1976, 1 ff.). Hodson does not mention that linear methods require very long computation times if the data sets are large, and that non-linear methods require still longer times. Classic approaches in factor analysis quickly become unwieldy even for moderately large data assemblages. A considerable advantage in linear techniques lies in the fact that there is only one unique solution, and this is rightly stressed by Hodson. Sensitivity to errors in the data is not discussed however. Principal coordinate analysis which may avoid this pitfall by suitable choice of a similarity coefficient is an attractive alternative to non-linear treatment, and it combines some of the virtues of both methods. Clear details of principal coordinate analysis are not given, and the reader has to refer to the specialized work of Gower (Some Distance Properties of Latent Root and Vector Methods Used in Multivariate Analysis. Biometrika 53, 1966, 325 ff.) which he will probably find quite heavy going. The method seems to be equivalent to a non-linear pretreatment of the data followed by a linear transformation, perhaps with a subsequent non-linear step after completion. This seems a useful way to deal with the problems of non-unique solutions.

Factor analysis has been one of the methods most favored by the American and French school. Perhaps they are popular, because there are many computer centers with standard statistical packages for the social sciences which include these techniques. Hodson notes Gower's opinion that the results of factor analysis are often close to those obtained with principal component analysis. It is rather unfortunate that most of the practical discussion in chapter eight is only illustrated by real examples in chapter nine. The reader must continually flip back and forth for text in one chapter and illustrations in the other.

Hodson notes that it is totally inappropriate to use factorial methods for clustering, quoting no less an authority than M. G. Kendall, the pope of recent mathematical statistics. The version known as varimax rotation is described in some detail with a comparative example from principal component analysis. The problem of deciding how many factors to consider is mentioned. The author notes that 'almost any body of data, if required, would produce varimax factors that would correspond to a certain extent with simple structure, but this wouldn't mean that the exercise in any way made sense'. That can be said of almost any data analysis technique blindly applied. Hodson follows this with a scathing critique of Binford and his use of the method (S. R. Binford, L. R. Binford, A Preliminary Analysis of Functional Variability on the Mousterian of Levallois Facies. Am. Anthr. 68, 1966, 238 ff.). 'In fact', says Hodson, 'the general impression conveyed by Binford's paper is that a method intended to simplify data has resulted in greater and unnecessary complication'.

A discussion of rotational fitting and constellation analysis, methods especially suited to studies of assemblages where the same constituents may be classified in different ways follows. It is much clearer than the description of discriminant and canonical variate methods. These last techniques are applied to cases where the units are already in valid groups and where they are designed to discover and emphasize attributes which discriminate between them. When discriminant analysis is extended to more than two groups, using procedures similar to principal component methods, one obtains canonical variate analysis.

One of the best known methods used in numerical applications in archaeology has been popularized by Hodson himself. This is the use of non-metric multidimensional scaling. Hodson refers the reader to Kruskal's 1971 description of the widely distributed program MDSCAL and gives a few details on how it works. He stresses the danger of arriving at local minima and the need for repeated runs on the same data. The unsophisticated reader should be warned that unless large amounts of cheap computer time is available on a big machine, that this technique will cost him a lot of money. Non-metric multidimensional scaling reduces concepts of scale in higher spaces to rank orderings. Hodson thinks that this can potentially sacrifice information. In fact it does, but it also reduces sensitivity to errors in the data at the same time. The important distinction made by Sibson between local and global scaling is not discussed.

Chapter nine gives practical examples using some of the techniques described in chapter eight. A set of 30 La Tène fibulae from Munsingen are treated with principal component, factor, varimax rotation, and discriminant analysis. They are subject to single link, double link, average link, and k-means clustering, submitted to MDSCAL and all these compared with classifications produced by hand by an anatomist and by four archaeologists. In short, these must be about the best studied thirty archaeological objects anywhere! Hodson concludes that most of the numerical procedures can produce results which are acceptable to the archaeologist although not all are equally satisfying. A similar series of tests is performed on Hallstatt C swords, paleolithic handaxes, trace element analyses in bronzes and faience beads taken from Hodson's earlier publications. One

most important feature which emerges from all this is that the critical examination of the input data and the choice of attribute is essential. Archaeological prudence cannot be replaced by shotgun statistical analysis.
It seems questionable to test different methods with real data whose underlying statistical properties cannot be known. In a recent paper, the reviewer and his colleagues pointed this out (Graham, Galloway, Scollar, op. cit.). We tried to develop simulation methods for creating artificial data whose properties were entirely known and which resemble real data. Results in testing seriation methods showed that some methods are very data dependent indeed, although all gave more or less similar answers. One always has the uncomfortable feeling that Hodson's data is so carefully selected before submitting to the computer that it is far more docile than usual. The simulated data behaves more like less well prepared material.
The results in chapter nine are not well displayed. More attention is paid these days to computer graphics for displaying things. Given modern methods in this field, results can be made much more intelligible for the non-sophisticated reader. There is no discussion of the need for programs which check the input data for errors in transcription. Although such programs are not very interesting scientifically, they are absolutely essential when large quantities of data are involved, and they are surprisingly difficult to write well.

The remaining four chapters in the book are by Doran. Chapter ten purports to be devoted to 'automatic' seriation. If ordering only is wanted, Doran thinks that some form of scaling is all that is needed. The reviewer cannot agree with this statement. Doran does not comment on the fact that good data for very large seriations is quite rare, but even a glance at the literature will show that this is the case. He notes that seriations may just as well reflect differences in location, function or social class and thinks that this can be overcome by using material from a single locality, a single cultural tradition, or by choosing chronologically suitable traits. Lucky indeed is the archaeologist who can fulfill these requirements! It is quite rare to find sites which have sufficient material for the first, for the second there is little way of telling what kind of a mixture one has, and the third is begging the question. If they know the chronologically suitable traits in the first place, then most archaeologists will not feel the need to do machine seriation.
Doran distinguishes between 'chronological seriation' and 'simple ordination', but the distinction is not clear. He discusses Kendall's work, but unlike Hodson passes over Sibson and Wilkinson in silence. He does discuss permutation of the similarity matrix using methods derived by Brainerd and Robinson, and notes Kendall's proof of the equivalence of this and work on the incidence matrix. For incidence matrix techniques, the sum of ranges over columns as a score for measuring concentration on the diagonal to use in permutation techniques was probably first thought of by Goldmann, but Doran seems to have thought of it independently. Doran does not criticise the 'rapid' seriation methods of Ascher, Renfrew and others in detail, but he notes that large matrices using these approaches require a computer anyway, so that one might as well use techniques with a better mathematical justification. He fails to note that the main problem in the Ascher, Renfrew approach is the treatment of ties, i. e. what to do when two equal decisions are possible. These techniques have no way for resolving such conflicts which do occur frequently in practice.
Doran mentions the problem of applying 'external evidence' such as stratification to seriation problems, and he notes the problems which arise when there are strong variations in richness, type abundance, highly correlated types, highly significant types and highly similar types, but he doesn't seem to have read Hodson's discussion in the previous chapter. Certainly the problem of type definition is a key in any seriation study and practical details have not received the full analysis deserved. The reviewer believes that there are no unique solutions. Probably some sort of interactive system, whereby the archaeologist can see many results in quick succession, may lead him to eliminate bad or doubtful data and weight others to obtain improvement.
Doran doubts the archaeologist's ability to reduce seriation to ordination by data selection. He thinks that really large problems can only be handled by iterative search techniques, but he does not mention that these methods are subject to severe local trapping, and worse yet, local reversals of sequences. There is no discussion of storage reduction techniques for sparse data matrices or of coding techniques for rapid data access. These matters are beyond the intended reader, but their existence should be mentioned here. On the whole, chapter ten is a weak discussion on a rich topic, and it is devoid of concrete illustrations.

Chapter eleven is devoted to mathematical models and computer simulation. Doran descends wrathfully, and rightly in the reviewer's opinion, on Clarke (Models in Archaeology [1972]) and those who have followed him. Doran notes the equal usefulness of a model or an ad hoc goodness of fit function and claims that the choice between them is an aspect of the choice between data analytic methods und classical statistics. Random walk processes are illustrated by the Ammerman model for the introduction of agriculture as a small local migration process with branching (A. J. Ammerman, L. L. Cavalli-Sforza, A Population Model for the Diffusion of Early Farming in Europe, in: C. Renfrew, ed., The Explanation of Culture Change [1973] 343 ff.). This leads to computer simulation as a check on mathematical reasoning and he suggests that this be opposed to looking for laws of cultural evolution. 'Ideally there would be no laws of cultural evolution . . . unfortunately it is unlikely to be that easy. It seems unduly optimistic to assume that such laws will be discovered if only we look a little more carefully. It can just as well be argued that their non-appearance to date strongly suggests that they do not

exist'. This reviewer wishes to point out to Doran that there is no shortage of literature which deals with presumed laws of cultural evolution. Their discoverers, whatever their persuasion, will be highly irritated to find out that Doran has dismissed their ideas as being non-existent. This view reflects the inherent bias of those who J. Weizenbaum has impudently called the 'artifical intellegentsia' (Computer Power and Human Reason [1976]). Although it may be possible that programming is a good medium for expressing poorly understood and sloppily formulated ideas (M. Minsky in: M. Krampen, P. Seeitz, eds., Design and Planning 2 [1967] 120), it does not necessarily follow that some fuzzy mental models presented in the literature are any further from the truth than are the computer simulations. Doran sums up by saying that 'it seems to us that comparatively little of real archaeological value has yet come from modelling work'. A fundamental difficulty is that 'the models which are mathematically tractable are too simple for most archaeological problems'. The reviewer wishes to point out that simulation is meaningful only if ample and reliable real data are available to control things, and this requirement is but rarely met.

Chapter twelve discusses computer based data banks in archaeology. Here the machine is used as a sophisticated filing system. This is one application of computers which many archaeologists unthinkingly accept since it is non-mathematical in nature. However, an archaeological data bank has rarely been implemented in a satisfactory way. The problem is that there is usually too much data for machines at hand, too slow a response time, inadequate security, lack of natural language question and answer techniques and lack of simple statistical analysis incorporated in the system. The author doesn't point out these shortcomings in detail. There is no review of the actual methods used to organize an information retrieval system and no adequate references are given. There is no mention of inverted file and hash code techniques, as opposed to straight search, and none of Boolean combinations of queries, with parsing of questions. There is a low level presentation of data input and output, together with problems of editing. That is all. Things have gone much farther during the time between Doran's writing and the preparation of this review. Doran does discuss the problem of descriptive coding which bedevilled the literature during the sixties. 'The real dilemma when constructing descriptive codes for archaeological material is that the more objective and scientific the code, the more cumbersome and impracticable it is' he says. How true, and a critique of the French school which has unfortunately devoted years of effort to this blind alley is implied. In connection with data banks Doran mentions computer networks and their advantages. He does not describe the frustration which the users of such a network sometimes experience due to limited reliability. In fact, nowhere in the book is the agony of actually using computer methods adequately described. Anyone who implies that the computer will save him effort should be condemned to working with them constantly, in the reviewer's opinion. Better still, he should own one!

The final chapter deals with the overall role of mathematics and computers in archaeology. Doran rejects discussion of computer applications in the physical sciences used to help archaeology (computer evaluation of geophysical measurements made on archaeological sites, for example) as being 'out of the main stream of development of mathematical methods in archaeology'. The reviewer is of the opinion that many of the most concrete and useful applications have taken place exactly in this area, but he is prejudiced by his own work. As far as the other methods being in the 'main stream' is concerned, they are in fact used only by a very small coterie of devotees whose work is unacceptable or unknown to the vast majority of archaeologists. To convince some of these sceptics it might have been useful to include some of the work in the auxilliary sciences, apart from the radiocarbon statistics discussion already mentioned. Doran notes 'the immense academic gulf between mathematics and archaeology', and that such work as has been done has come mainly from the geographic, anthropological and social sciences. He is especially critical of archaeologists who hopefully approach a mathematician or statistician who knows as little as they do about archaeological problems in statistics, but who they treat as an expert. He rightly warns the archaeologist to be critical of the expert chosen and notes that the techniques used today 'have come from a diversity of peripheral branches often themselves new and at best uncertain in application'. Archaeologists are to be made aware of the fact that 'there are specialities in math which are figuratively as far apart as paleolithic and industrial archaeology'. The reviewer agrees heartily.

There is a considerable difference between the practical view that there are certain aspects of archaeological work which can be treated mathematically and the views of the 'New Archaeology'. Doran says 'Alas, it is so much easier to make theoretical play with exciting, if a little imprecise, general concepts than to get down either to actual mathematics or the solid and detailed practical application'. This is the healthiest warning in the book. Doran feels that every archaeologist should know how to use simpler methods of quantification and the potentials and limitations of the more sophisticated methods. He notes that the use of computers requires putting one's thoughts in order in a severe way, and that what is completed is more objective and solid. The reviewer may be excused for noting that when the archaeologist puts his data in such very good order for the computer and when all works out, he usually understands it so well that he doesn't need the machine except to confirm his judgement. Maybe that isn't such a bad thing. Doran feels that there is a real need for a new class of specialists who guide the archaeologists in the new methods, and the reviewer again agrees completely.

To sum up this review: this book has some shortcomings. However, it is the only comprehensive attempt do deal with a subject which archaeologists find very difficult. It touches on many different problems pointing out limitations of method and indicating the direction which interested readers should take. It is highly readable for the most part, and free of jargon or naive bias in a field where such virtues are rarely encountered. It should be read by all who wish to understand the new methods which have emerged during the last generation. This must have been a hard book to write. Some time ago, the reviewer opened with a similar phrase concerning David Clarke's 'Analytical Archaeology' with read substituted for write. Both were hard to review. At least this one was easy to read.

Bonn I. Scollar